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CONTENTS.

THE NERVOUS SYSTEM.

INTRODUCTION.

THE bodies of all the higher animals are composed of many parts or organs, each of which in performing its own duty ministers to the common good; but in this division of labour, which is necessitated by the complicated conditions of their life, the nervous system stands out

> In noble eminence enthroned and sphered above the other;

unrivalled in the delicacy of its structure, and unsurpassed in the value and importance of the purposes it fulfils. Without the nervous system it is impossible that animals could ever have acquired their present complexity of structure, since they would be destitute of the means by which their organs are brought into relation with each other and are enabled to work together in harmony. To it all parts are subservient. The alimentary canal, with

its vast system of glands and assimilating organs, serves essentially to absorb and elaborate the materials for its nutrition. The circulating system conveys to it the substances thus carefully prepared, together with oxygen inhaled by the respiratory organs, whilst the same ceaseless current constitutes also the means by which the products of its disintegration are carried away. Lastly, the bones and muscles form together the system of levers by which it reacts upon the outer world, and effects such change of place as may be required for the procurement of fresh air or food. Every structure is under its control, and like a rider on his steed it influences and regulates every action of the bodily organs. Through it man recognises that he is something separate and distinct from his environment. With its growth and development our powers over the forces of Nature increase. It is the centre from which the mandates of the will emanate. It is the seat of conscience, the organ of thought and reason.

In all animals it is jealously guarded from external injury, and in the higher classes special provisions are made for its preservation. In these it is surrounded by a bony case of singular strength, exquisitely constructed to resist violence ; and it is further secured from injury by an internal leathery covering—the *dura mater*—within which is a double membrane—the *arachnoid* softer and

more delicate than the finest silken fabric, the opposed surfaces of which are lubricated with a fluid to reduce friction, whilst it may almost be said to float in fluid, so close is the network of vessels filled with blood in the innermost membrane—the *pia mater*—by which it is enclosed.

The knowledge of the nature and offices of this system was long shrouded in darkness, and notwithstanding what appears to us from our present standpoint the clearest evidence, its predominance in the specially animal faculties long remained unrecognised. In the Hebrew as well as in the Homeric writings, the blood is uniformly regarded as the life of animals and of man; for both priest and warrior saw the death agony of the victim or of the vanquished follow its loss, and not unnaturally attributed those convulsions which are really due to the failing powers of the nervous system to the escape with the blood of the vital or animating spirit, which they believed to be contained in the arteries. Recent experiments, however, have shown that even in an animal so highly organised as a frog, the blood may be wholly withdrawn from the body and replaced by artificial fluids, without, for a time at least, materially interfering with its vital activity; whilst, on the other hand, a wound in a particular region of the nervous system, so small as to be almost invisible to the naked eye, and unattended

with the loss of any appreciable amount of blood, will strike down the strongest animal, and arrest at once and for ever the activity of every part of the body.

So little significance was anciently attributed to the most important portions of the nervous system, that the brain was regarded by Plato as only equivalent to the marrow of the bones; whilst Hippocrates, whose anatomical knowledge was much limited owing to the superstitious veneration paid by the Greeks to the dead, believed it had no other use than to secrete the pituita of the nose, and everywhere confounds the nerves with the tendons and fasciæ of the muscles. Even Aristotle, whose authority reigned supreme for so many years wherever science was cultivated, and whose knowledge of zoology was so far beyond many of his successors, taught that the nerves sprang from the heart, and that the chief office of the brain was to cool the heated blood. By degrees, however, and through the sure channels of repeated and carefully conducted observation and experiment, more correct views began to be established. Three hundred years before Christ, Herophilus and Erasistratus, under the rule of the enlightened Ptolemies, founding their statements on actual dissection, demonstrated the origin of the optic and other nerves from the brain, and pointed out the relation that exists between the development of the various faculties and intellectual powers, and the extent and number of

the cerebral convolutions. It is to Galen, however, that we are in an especial manner indebted for establishing many of the principal facts that are now generally accepted in regard to the functions of the nervous system, and it is worthy of remark that his knowledge rested on experiments performed upon the living animal. After Galen, physiology slept a long sleep of a thousand years, and awoke only with the period of the Renaissance of knowledge in Europe, when the persevering and intelligent labours of Fallopius, Eustachius, Vesalius, and Descartes first advanced the knowledge of the nervous system. The functions of the brain and spinal cord soon began to be understood, though even up to the time of Buffon, at the close of the eighteenth century, the nerves were held to be tubes traversed by a fluid, whilst the brain was only an organ which supplied the nerves with their proper aliment. It has been reserved for observers of our own time, aided with the appliances afforded by chemistry in the form of staining agents, and by physics in the microscope, to pursue their investigations upon the structure and functions of the nervous system with success, to show the exquisite delicacy of its minuter parts, and the marvellous adaptation of structure to function that everywhere obtains; and still new points of interest appear, as the subject is examined with improved instruments and better-instructed minds.

Important as are the purposes fulfilled by the nervous system in the higher classes, we find as we descend to the lower forms of animal life that it becomes less and less specialised, till at length we arrive at creatures so lowly organised that it becomes impossible to recognise it as a distinct system, though its presence in a diffused form may be surmised from the phenomenon of movement on the application of a stimulus being propagated to some distance from the point actually stimulated. Some such obscure indications of a nervous system may be observed even in the vegetable kingdom, though the stationary habits of plants, the absence of any necessity for active movement to enable them to obtain their food, or to perform the functions of respiration and circulation, has militated against the development in them of a specialised nervous system.

Many parts of plants, as the radicles, the young stems, the tendrils, the leaves, the stamens, and seed vessels, are irritable, that is, they respond to direct stimulation by movement. So long as the motion is confined to the part irritated it may be maintained that it is due to the contractility of the particular cells touched or stimulated; but when parts remote from the point stimulated exhibit movement, the stimulus must be conducted in some way or other to this distant part, and the tissue through which the conduction takes place discharges the office, though

it may not present the structure of the nervous tissue of animals.

Evidence has recently been adduced by Darwin showing that even the radicles of plants, parts that have not hitherto been supposed to possess any higher attributes than some power of selection ordinarily expressed by saying that this or that soil or climate suits particular species, are in reality very highly endowed; for if the tip of the radicle be lightly pressed, burnt or cut, it transmits an influence to the upper adjoining part, causing it to bend away from the affected side; and, what is more surprising, the tip can distinguish between objects of different degrees of consistence by which it is simultaneously pressed on opposite sides. If, however, the radicle is pressed by a similar object a little above the tip, the pressed part does not transmit any influence to the more distant parts, but bends abruptly towards the object: moisture, light and heat, each exert a special and well-marked influence on the radicle. Here we must suppose that some influence is transmitted from the apex through the intermediate tissue, and this it is impossible to regard otherwise than as performing a duty identical with a nervous system, though its structure may be different. And Mr. Darwin actually maintains that it is hardly an exaggeration to say that the tip of the radicle thus endowed, and having the power of directing the movements of the adjoining

parts, acts like the brain of one of the lower animals, the brain being seated within the fore-part of the body, receiving impressions from the sense organs, and directing the several movements. Equally marked instances of response to stimulation of distant parts are seen in the movements of the leaflets of the sensitive plant when the petiole or stem is touched, and in the movements of the leaves of the Venus's flytrap.

We shall endeavour in the following pages to give a concise description of the principal features of the structure and composition of the nervous system, and an account of the modifications it presents in the animal kingdom. We shall then be in a position to understand the modes in which its activity is called into play, and to comprehend the offices it fulfils in the animal economy. In conclusion, an attempt will be made to give a brief description of the several faculties of animals and of man, with the best mode of ensuring their healthy development and use.

THE CHIEF FEATURES OF THE NERVOUS SYSTEM FROM AN ANATOMICAL AND CHEMICAL POINT OF VIEW.

The essential parts of the nervous system in all animals in which this system is clearly differentiated from the other structures and organs of which the body is com-

posed are two in number, *nerve-cells* and *nerve-fibres.* There are indeed certain accessory parts that are always found in the nerve-centres, and in the nerve-fibres when these are massed together to form cords of a certain size; but such parts must be regarded as incidental, and not as essential tissues. Thus it is requisite that both the nerve-cells and nerve-fibres should receive a sufficient quantity of nourishment and of oxygen, without which there can be no sustained activity; hence they are supplied by channels containing blood, the cells freely, the fibres more sparingly, and by a beautiful provision the same means that minister to the oxidation and support of these tissues are subservient to the removal of the waste products of their action, which, if allowed to accumulate, would rapidly impair and ultimately abolish their activity. At the terminations of the nerves, again, certain peculiar organs are found which are fitted for the performance of special duties, and which differ in the case of each special sense: the terminal apparatus of the nerve distributed to the eye, for example, differing from that of the ear, and this again from the terminal apparatus of the nerves supplying the skin and the tongue. Such differences in the structure of the terminal organs are not present in the lower animals, and are only gradually superadded to, or differentiated from, the fundamental parts with the increasing complexity of the particular organs in question.

Lastly, in the central parts of the nervous system of the higher animals a considerable quantity of finely granular, or perhaps if it were possible to magnify it sufficiently, finely fibrous material is found between the cells, the use of which is unknown; they are also separated more or less by connective tissue, which is believed to sustain and support the more delicate nervous tissue.

Apart from these accessory organs and tissues, however, the nervous system as a whole may be said to be composed of two mutually dependent parts, the nerve-cell and the nerve-fibre, the nerve-fibre being in truth only a modified process of the cell itself. It is of great importance that a clear conception should, in the first instance, be obtained of the nature of these two parts.

NERVE-CELLS.—From an anatomical point of view, a nerve-cell is a small mass, too small to be recognised by the unassisted eye, of a substance named protoplasm, endowed with properties of a very remarkable kind. In the young state the cells are rounded or slightly polygonal from mutual pressure, and their outline is faint and ill-defined; but in the mature state they become more or less hardened on the surface, and their form undergoes considerable alteration, varying with the conditions under which development has taken place, being rounded, oval, or spindle-shaped, or polygonal, or sending out processes from several parts of the surface, when they are said to

be branched or ramified. Whatever their form may be they still present the same parts, which may be understood from a consideration of Fig. 1, which represents a young cell. First of all, forming the body of the cell, is the protoplasm, the outer part of which is more or less hardened, and constitutes the part named the cell-wall: near the centre is a small body, like a cell within a cell, named the kernel or nucleus, and in the interior of this again are one or two tiny spots named nucleoli.

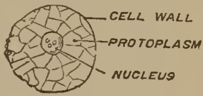


Fig. 1.

A few years ago the substance here termed protoplasm was considered to be perfectly homogeneous and uniform, but recent inquiries have shown that it is of more complex constitution; and no better example can be given to illustrate its structure than a ganglion-cell taken from the electric lobe of the brain of a Torpedo. This is seen to be a body of well-defined but very ir-

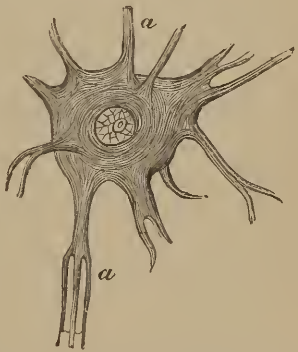


Fig. 2.—Stellate or branched Nerve-cell from electric lobe of Torpedo. It contains a nucleus, and gives off many fine fibres, one or two of which (a) become nerve-fibres.

regular form, the substance of the cell running out into long arms or processes, and being traversed in every direction by fine fibrils, imbedded in confused granular substance. In the centre is seen the clearer or brighter nucleus, which is also finely dotted, and presents a few faint lines and a minute central spot or nucleolus. The arms of the cell are not all of equal value or importance. Most of them if traced outwards from the cell divide and subdivide, and at length become so slender that they are utterly lost in the ground substance between the cells, which therefore forms a bond of connection between neighbouring cells. One or two, however, represented at *a*, have a different destiny, and become the *nerve-fibres* connected with the nerve-cell, which proceed either to other cells or to some more or less remote organ, as a gland, a muscle, or an organ of sense.

GANGLIA.—When several cells are gathered together into a little heap, which is covered by a membrane or sheath, it is termed a ganglion, and such a ganglion is shown in Fig. 3. Several cells are here shown; each gives off two fibres at its opposite poles, and is hence termed bipolar, or if there are more processes, multipolar. The investment which keeps them compact is also shown; to complete the picture, we may add a small bloodvessel conveying blood to the cells by means of its branches. And simple as this structure is, it presents almost all the

features that characterise the highest centres of the most perfectly-developed brain.

Nerves.—We must now turn our attention to the nerves. The nerves are white cylindrical cords composed

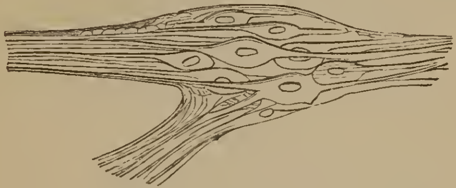


Fig. 3.—A Nerve-ganglion.

of a greater or less number of nerve-fibres. They vary in thickness in man from the great sciatic nerve which runs down the back of the thigh, and is nearly as large as the little finger, to others so small as to be quite invisible to the eye. They are very tender and easily broken near their origin in the centres, but become invested with a strong sheath named the neurilemma, in parts like the limbs where they are to a certain extent exposed to injury. The sheath confers upon them a considerable amount of resistance and tenacity, but they possess little elasticity.

Nerve-fibres.—When a nerve issuing from the spinal cord or brain is quickly taken from the body of an animal just killed and after being teazed out with needles is examined under the microscope, the fine threads

of which it is composed appear to be transparent and structureless, but after being treated with various reagents, some of which stain one part and others another part, each nerve-fibre may be shown to consist of three concentric layers, diagrammatically represented in the adjoining woodcut. The innermost of these, or the core of the nerve-fibre, is the *axis cylinder*. This is surrounded by a layer of fat-like substance named the *medullary layer*, and this again is enclosed by a very delicate membrane named the *sheath of Schwann*, after the anatomist who first recognised and described it, and which serves to bind the whole fibre together, to give it strength, and to afford a certain amount of protection from injury. The precise use of the medullary layer is not known, but it is highly probable that, like the layer of gutta-percha covering a telegraph wire, it serves to isolate the core from adjoining fibres. The core itself is the essential part of the nerve-fibre; it alone is connected with the special structures at each end of the fibre, whilst the two others are never thus connected, and are sometimes absent throughout the whole length of the fibre. The examination of nerve-fibres after special modes of staining have been applied, shows that certain

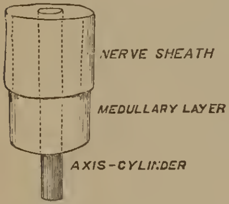


Fig. 4.

interruptions occur at tolerably regular intervals, caused by a thickening of the sheath or membrane, the white medullary layer being thus separated into blocks. When nitrate of silver is used as the staining agent, some transverse lines are seen in the axis cylinder, near the node, the nature of which is not at present known. Delicate as the axis cylinder is, there is good reason to believe that it really consists of a bundle of extremely fine fibrils, each of which has its special destination. These fibrils are so small that they require a high magnifying power to see them, and perhaps as many as 100,000 could be placed side by side in the space of one inch.

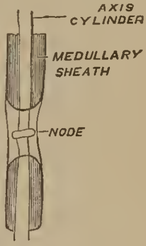


Fig. 5.

Sympathetic System.—The nerve-cells and nerve-fibres that have hitherto been described really constitute the brain and spinal cord, and are hence termed cerebro-spinal nerves, or the nerves of animal life, because it is through them that we call the muscles into action, and that we feel, see, hear, taste and smell, as well as exercise the higher intellectual functions; but there is another system of nerves, which is in great measure but not altogether independent of the cerebro-spinal nerves, and which is known as the sympathetic system, or the nervous system of vegetative life, because the fibres are chiefly distributed to the organs of nutrition, as to the alimentary

canal, lungs, and heart. The system as a whole is characterised by the large number of ganglia it presents, and by some peculiarities of the nerve-fibres.

In vertebrated animals it consists of two series of ganglia connected by cords which extend along each side of the spinal column. The branches from the ganglia in part run to join the cerebro-spinal nerves, but chiefly unite to form three principal plexuses, named respectively the cardiac, the cœliac, and the hypogastric plexuses, which are placed in immediate relation with the heart, the stomach, and the organs contained in the pelvis. These nerve-fibres present a peculiar grey or reddish grey aspect when united to form a nerve-trunk, and when such trunks are examined under the microscope they are found to be composed in part of fibres like those of the cerebro-spinal system, but in part also of peculiar fibres having an investing sheath and an axis cylinder, but no medullary layer. They have also many small oval bodies named nuclei imbedded in the external sheath.

Fig. 6.—Sympathetic Nerve-fibre.

Neuroglia.—In all nerve-centres the intervals between the rounded cells is filled with a finely granular substance which is now believed to consist of an interlacement of extremely fine elastic fibres with star-shaped cells, and has received the name of neuroglia, signifying nerve-jelly.

Modes of termination of Nerves.—This, which is one of the most difficult problems in microscopic research, still presents some points that have not been satisfactorily determined; and each successive step in the penetrating power of the microscope, in the discovery of new staining agents, and in the care with which observations are made, and the acuteness with which the appearances seen are interpreted, has disclosed numerous features of unexpected interest.

At one time it was generally believed that every nerve forms a loop, one branch of which passes from a nerve-cell towards the part to which the nerve is distributed, whilst the other branch or limb of the loop returns to the nerve-cell, and this may possibly be the case in some instances. But there is no doubt that in many parts the nerves terminate in free extremities, and perhaps the nearest expression of the truth is that the nerves terminate generally in free extremities, but that these extremities present specially-formed end or terminal organs differing for each sense, which are adapted to enable them to perform their particular duty.

Taking the several senses in the order of touch, seeing, hearing, smelling, and tasting, we find that in the skin the fibres form a close plexus or network at a short distance below the surface, from which delicate fibrils are given off that extend almost, if not completely, to

the free surface. The skin covering the body generally is composed of so dense and thick a network of another kind of fibres, that it is extremely difficult to follow the ultimate fibres of the nerves to their destination; but there is one part which is transparent, and is at the same time extremely sensitive, the cornea or glass of the eye. The sensitiveness of this part is proverbial. "Small things," as young Arthur pleads to Hubert, "are boisterous there;" and it has been shown that fine nerve-fibrils may here be traced up to the surface, and being exposed perceive acutely the slightest touch, even that of "a grain, a dust, a gnat, a wandering hair." Similar free extremities have lately been observed in the skin of other parts of the body; in addition, some very peculiar organs have been described, which appear to have some special functions. The simplest of these is shown in Fig. 7, where the nerve appears to end in a bulbous enlargement which is found to consist of a dilatation of the sheath, thus forming a little sacculus containing fluid; the sac appears to be composed of an expansion of the outer sheath of the nerve, whilst the axis cylinder runs up the centre, and terminates by a free end. This arrangement is eminently adapted to enable the nerve to respond to slight vibrations.

Fig. 7.—A Corpuscle of Vater

In another mode of termination that has been noticed

in the skin, the nerve terminates in a body termed a "Pacinian corpuscle," which is clearly the same as the preceding form, only somewhat increased in complexity, for instead of a single capsule there are a series. These corpuscles are found most frequently in the skin of the palmar surface of the fingers. Their use is unknown, but it is possible that they may be designed to respond to variations of temperature, in regard to which the skin is very sensitive, or perhaps to those light touches which produce the sensation of tickling.

Fig. 8.—A Pacinian body.

Another and more common mode in which the nerve terminates in the skin, is in "tactile corpuscles," one of which is shown in Fig. 9. These "touch-bodies" are apparently solid, and present an ovoid form, the ultimate branches of the nerve coiling round them, and being either lost near the extremity or possibly forming a loop at this part. It must not, however, be supposed that these bodies are essential to the exercise of the sense of touch, since although in the case of the fingers and toes, which are highly sensitive, they number twenty or more in an area which is not more than one twenty-fifth of an inch on

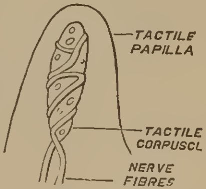


Fig. 9.—A Tactile Corpuscle.

the side, there are only one or two in the same space in the palm and sole, and they are scattered very sparingly in the skin of the forearm, arm, and thigh, which are nevertheless all very sensitive parts; in these parts the modes of termination by free extremities probably pre dominates.

Fig. 10.—A Taste Bud, the component parts of which have been separated from each other.

In the organ of taste, which appears to be only a slight modification of the organ of touch, the nerves terminate in peculiar end buds, Fig. 10, composed of two sets of cells, an outer set (*a*, *c*), which are flat and curved and by their apposition form a kind of box enclosing the inner set; the latter (*b*) are slender nucleated filaments; probably both sets of cells are continuous with nerve-fibres.

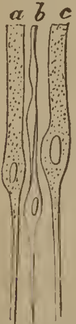


Fig. 11.—The termination of the nerve in the organ of Smell.

The organ of smell occupies a part only of the interior of the nose, and this part is recognised by the peculiar yellowish or brownish tint it presents in the recently-killed animal. The ultimate fibres run up between the cells of the surface and end in rod-like bodies, some of which (*a*, Fig. 11) are

thicker than others (*b*); the more slender ones probably constitute the sentient fibres, and have been seen to be connected with nerve-fibres.

The mode of termination of the nerves in the retina, or organ of vision, will be given in detail in the volume of this series devoted to the eye, but it may be stated here that the fibres of the optic nerve, as soon as they have entered the globe of the eye, radiate in all directions, and are, most or all of them, connected with large ganglionic cells (*a*), from which they may be traced for some distance through the several layers of which the retina is composed, and are then lost, though there is reason to believe that they are in direct continuity with special organs named rods and cones (*b*), which are imbedded in pigment (*c*). Where the retina is detached from the bed of pigment on which it lies, as occurs in some cases of accident, vision is lost. Some physiologists have thought that the black pigment absorbs

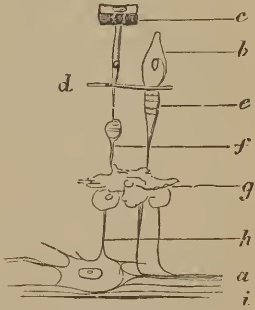


Fig. 12.—A section of the Retina.

a, large ganglion cell; *b*, rod and cone layer; *b*, points to a cone, beyond the cone is a rod; *c*, pigment cell; *d*, external limiting membrane; *e*, external granule layer; *f*, external molecular layer; *g*, internal granule layer; *h*, internal molecular layer; *i*, internal limiting layer.

the rays of light that fall on the retina and convert them into heat, which is the motion that is really perceived.

The mode of termination of the auditory nerve in the ear is still more difficult to follow than in the eye, for this organ of sense is imbedded in an extremely hard bone, which requires to be softened with acids and otherwise prepared in order that sections appropriate for examination under the microscope may be obtained. The most reliable researches that have been made seem to show that the fine nerve-fibrils end in very peculiar cells, from the surface of each of which a small bunch of bristles protrude. These are the bodies which appear to respond to the stimulus of sound, but the facts at present known are insufficient to permit any positive statement to be made.

In the muscles, which are organs that receive a large number of nerve-fibres, the nerves first form a plexus or network with rather wide meshes, that embraces the muscular fibres, and from this network separate fibres are detached which terminate in "motorial end plates." In these, as shown at *c*, in Fig. 13, the dark-bordered nerve runs up to the muscular fibre, and first loses its outer sheath, which becomes continuous with the sheath of the muscular fibre, and then the medullary layer, whilst the axis cylinder penetrating the fibre forms a clear expansion near the surface, beneath which is some granular

matter containing bright clear nuclei. Nerve substance and muscle substance here appear to blend with each other, and it is evident that the immediate and direct action of the nervous system on the muscle is secured.

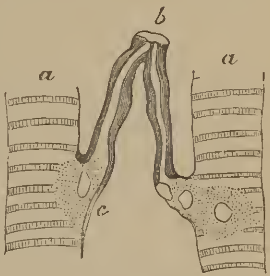


Fig. 13.—Termination of Nerve in Muscle.

a a, two *striped* muscular fibres; *b*, a nerve-fibre dividing into two fibrils; *c*, a motorial end plate.

The mode in which the nerves terminate in smooth muscles like those by which the movements of the stomach are effected, so far differs from that observed in the ordinary striated muscles of the limbs, that whilst the nerves run straight from the brain and spinal cord to the latter, in the former case the nerves invariably form a close meshwork before reaching their destination, and this accords with the different way in which the two kinds of muscle are called into action. It is important that the voluntary muscles should act separately and immediately in response to the mandates of the will, and hence the channels through which those mandates are transmitted run an uninterrupted course, whilst in the case of such muscles as those of the alimentary canal speed is of less importance, and it is requisite that long tracts should

successively contract. Hence plexuses or meshes, in which the fibres have a wide distribution, are present.

Lastly, in the glands, of which those secreting the saliva and the tears constitute good examples, the nerves either form loops, or, as some careful microscopists believe, penetrate the gland-cells, and are thus brought into direct relation with the protoplasm by which the act of secretion is effected.

Fig. 14.—A gland lobule with nerves supplying it. The lobule is shown containing seven cells by which the secretion is formed; at *a* are two stellate ganglionic nerve-cells, the branches of which pass to, or penetrate, the gland-cells.

Such are the principal modes in which the nerves end, and it is not surprising, considering the extreme delicacy of the ultimate fibres, that observers should not be perfectly agreed, and that some points still remain to be cleared up by improved instruments and better application of chemical agents.

The *chemical composition* of the nerve-centres and fibres is extremely complex, and very few facts of general interest can be stated in regard to it. It seems, however, to be well established that the axis cylinder or core of the fibre is composed of an albuminous substance, whilst the medullary sheath is made up of a fat-like substance which contains a considerable amount of phosphorus.

The investing membrane belongs to a class of compounds that yield gelatine on boiling. The reaction of a living nerve is neutral; that is to say, it neither turns blue litmus paper red, nor turmeric paper brown. It is heavier than water in the proportion of 1036 to 1000. It contains so large a proportion of water that when 100 grains of the brain are thoroughly dried, we only obtain a residue of from 15 to 20 grains.

The Nervous System of Animals.

The structure and arrangement of the parts of the nervous system in the animal kingdom are replete with interest, for they exhibit a series of experiments prepared for us by nature, in which we may observe the effects of a gradual increase of complexity, due in part to the multiplication of similar organs, and in part to the specialisation of certain parts which are destined to perform particular offices.

In the lowest forms of animal life it is impossible to discern any structure to which the term nervous can be applied. In the Amœba, and in the members of that class of organisms which stand on the border-land between animals and plants on the one hand and the inorganic world on the other, and to which the name of Monera has been applied, the nervous system appears to

be diffused through the whole body without possessing or being associated with any special structure. Every part is sensitive, and every part seems to be capable of transmitting impressions made on the surface to the rest of the body. Most of these creatures lead a vagabond kind of life, creeping slowly from place to place, seeking food and shunning light, gathering themselves up into a ball, and remaining quiescent, if touched or irritated, but spreading out and recommencing their movements when the effect of the stimulus has passed away. These relations seem to point to the possession by the whole body of a dull kind of sensibility; and it is interesting to observe that a sense of contact or common sensation, and a perception of the difference between light and darkness, or the visual sense, are the first indications of the existence of a kind of perceptivity which, whilst it can hardly be dignified with the name of consciousness, is something more than the mere reaction of inert matter to an external agent.

Interesting recent researches on the Medusæ, or jelly-fish, show that they possess an extremely elementary form of nervous system. Highly competent observers have failed to demonstrate any distinct nerve-fibres, though there is evidence that the undulating movements of the disk by which locomotion is effected are under the control of small bodies situated in its margin. If these

are cut away the disk remains motionless, unless directly stimulated, when a contractile wave starts from the point irritated and spreads to great distances. It seems probable that an imperfectly-differentiated nervous plexus is here present, along the lines of which impulses are propagated with greater facility than along the adjoining protoplasm; just such lines, in fact, as have been theoretically supposed to precede the formation of a true nervous system.

The next stage in the evolution of a nervous system is seen in the fresh-water Hydra. This little creature is common in stagnant pools in summer. It is usually to be found attached by its base to a floating leaf or fragment of vegetable matter, spreading out its arms, which are endowed with stinging powers, to catch its prey. If touched by some moving organism, a Daphne or Cypris for example, the prey is rendered powerless, and is then seized, not only by the arm by which it has been stung, but by the other arms, which bend down to enclose it. It is obvious that some impulse has here been propagated from one part of the animal to another, and careful examination has shown that the surface-cells of the hydra are composed of two parts

Fig. 15.—Neuro-muscular cells of Hydra.

The cup represents the sentient nerve-cell; the stand or base the muscle; the stalk the nerve-fibre.

having different functions, the outer part being sensitive, and the deeper part muscular—that, in fact, these cells are really compound, partly nervous and partly muscular; hence any stimulus applied to the surface originates an impulse which is propagated to the deeper part of the cell and excites it to contract, and the contraction then extends from one muscle-cell to another. In the next stage of complexity, which is presented by many forms of animal life, the nerve-cell appears as a distinct structure (*b*, Fig. 16) interposed between the superficial sensory cell (*a*), which represents a terminal organ specially adapted to receive impressions, and the muscular cell (*c*), with both of which it is connected by means of a fibre. In this case an impression made on the surface is conducted through the fibre to the nerve-cell and here produces a sensation, and the nerve-cell then originates an impulse which excites the muscle-cell to action. Instead of a muscle, it is easy to conceive that the nerve-fibre proceeding from the nerve-cell supplies a gland, which might thus be stimulated to secrete. We thus obtain the simplest notion of a reflex action, namely, that of an impulse which is conducted by a special nerve-fibre to a nerve-cell, and from

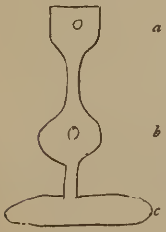


Fig. 16.
a, surface or sensory cell; *b*, nerve-cell; *c*, muscle-cell.

this is transmitted or reflected by another fibre to a muscle or gland.

In the star-fish, which represents a comparatively simple type of nervous system, the nerves may be traced along the arms, and are found to be connected with a ring situated in the body surrounding the gullet and presenting opposite each arm an enlargement composed of ganglion cells. There is reason to believe that one set of the fibres found in each arm is sensory, conveying impressions made on the sentient extremities to the ganglion in the body, and that from this ganglion impulses are propagated in the opposite direction, that is, towards the muscles, by the contraction of which the slow, creeping movements of the star-fish are effected.

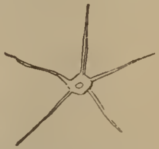


Fig. 17.—Nervous ring of the Star-fish.

In ascending to the next grade or type of organisation presented by the nervous system, two forms are met with which appear to present a nearly equal degree of complexity—that, namely, of the Arthropoda, comprehending the centipedes, insects and spiders, together with crabs and lobsters and their congeners, which numerically constitute by far the largest mass of animal life on the globe; and on the other the Mollusca, including animals like the oyster, snail, and cuttle-fish. In the Insects, as shown in Fig. 18, there is a chief or predominant set of ganglia in the head,

and a succession of smaller ganglia extending through the whole length of the body, and united by a *double* cord, the significance of which is great, for it shows that even in those instances where the ganglia are in the middle line and apparently single, they are in reality produced by the blending together or fusion of those on opposite sides of the body. There are three pairs of ganglia in the thorax, which govern the movements of the legs and wings in such animals as the fly or beetle, and six pairs of ganglia more or less coalesced in the abdomen. It is noticeable that the size and complexity of the ganglia are dependent on, or at least are associated with, the degree of sensibility and with the freedom of movements of the parts supplied; hence, since the wings and legs of articulated animals possess great mobility, the ganglia are large. The abdominal segments, on the other hand, move but little and are cased in a chitinous investment, and the ganglia are small.

Fig. 18.—Nervous system of a Beetle.

Large ganglia are found in the head, for in the head are contained the principal organs of sense, and also

certain ganglia which appear to possess a presiding or controlling, sometimes termed a co-ordinating, power over the rest, as may easily be seen by comparing the movements of a wasp before and after the removal of the head. Each of the ganglia forming the longitudinal chain in the thorax and abdomen of an insect receives sensory fibres from and gives off motor branches to its own segment. The spinal cord of man may be regarded as conforming to this type and to consist of a series of ganglia, the distinctness of which is obscured by the mass of fibres connecting them with each other, and with the governing centres contained in the brain. The higher forms of articulated animals present an additional set of ganglia and fibres known as the stomato-gastric system, believed to govern the movements and secretions of the intestinal canal.

In the second great group of invertebrate animals, the Mollusca, the arrangement of the ganglia and nerves is less regular and symmetrical, but this is due only to the altered position of the organs. Each important organ has still its own nerve-centre, receiving impressions from it by means of afferent fibres and issuing impulses to it through efferent fibres. The skin and mouth, the foot and the gills, for example, all of which are highly important organs in the mussel or periwinkle, have, as is shown in Fig. 19, their own ganglia.

The foremost ganglia of the Mollusca, which are situated above the gullet, seem to possess the same kind of controlling power over the rest that the ganglia in the head

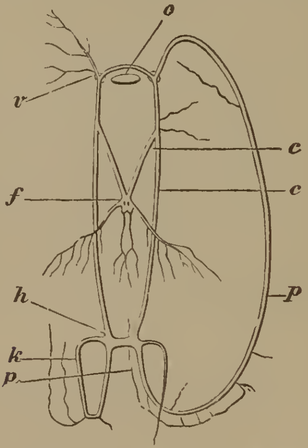


Fig. 19.—Nervous system of the Mussel.

o, mouth; *v*, anterior ganglion; *f*, foot ganglion; *h*, posterior ganglion; *k*, gill nerve; *p*, mantle nerve; *c*, connecting fibre.

of the insect exercise, but our knowledge on this subject is very limited. In the mussel the organs of sense are very imperfectly developed, but in the cuttle-fish, which possesses well-developed eyes and tongue, and much

tactile sensibility and power of movement in the body generally, the ganglia in the head are large and evidently govern the rest.

The step from the highest Mollusk, such as the cuttle-fish, to the lowest Vertebrate, the lancelet, seems to be marked by decreasing instead of increasing complexity of the nervous system. For in the lancelet we find only a simple tube running along the back, which resembles the spinal cord of the higher animals, but which presents no enlargement at its fore-part corresponding to a brain. In the higher fishes the form is such as is represented in Fig. 20.

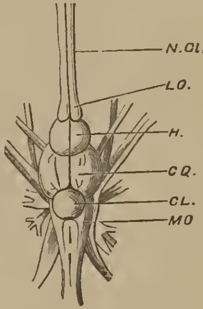


Fig. 20.—The Brain of a Perch seen from above.

n, ol., olfactory nerve; *l o*, olfactory lobe; *h*, cerebral hemispheres; *c q*, corpora quadrigemina; *c l*, cerebellum; *m o*, medulla oblongata.

In this type of nervous system we find a mass of ganglia collected together to form the brain, which is enclosed in a bony framework, protecting it from external injury. In front are the nerves and ganglia, ministering to the sense of smell (N. OL., L O), next follows a two-lobed eminence which seems to represent the cerebral hemispheres of man (H), then come the great centres of vision (C Q), to which the optic nerves are connected.

after these the cerebellum (C L), which associates and harmonises the movements of the animal, and finally the medulla oblongata (M O), which is itself a collection of many minor centres governing the functions of respiration, circulation, and nutrition.

Continuous with the medulla oblongata is the spinal cord, which, as already stated, may be regarded as the representative of the gangliated cord of the insect, except that the ganglia are all fused together into a continuous mass, and rarely act separately or alone. Little need be said of the nervous system of the amphibian, the reptile, or bird. The type of that of the fish is preserved throughout, though the different modes of life in the various classes lead now to this, now to that part, becoming larger in size and more complex in structure. Even in the higher apes the difference is one of degree only; the nerves and lobes of smell conformably with the little use made of that sense have become smaller, and appear only as rudimentary organs, but the parts homologous with H (Fig. 20) have undergone enormous enlargement in correspondence with the development of the higher intellectual faculties. The size of these parts, named the cerebral hemispheres, is so great as to outweigh the whole of the rest of the nervous system, and their complexity, as indicated by many layers and groups of cells, is no less strongly expressed. These must not be

regarded as mere multiplications of similar parts, though they are still composed of the same elementary structures, cells, and fibres. The fibres indeed remain unchanged as mere conductors, but the cells becoming arranged in groups of various size acquire new functions, fulfil new purposes, and react again on all the other centres.

Even in man the differences observed in the brain and spinal cord are those of degree only, and not of kind. The spinal cord (*a*, Fig. 21), as in the other vertebrates, is enclosed and protected by the spinal column. It is but a small body measuring fifteen inches in length, with a diameter of half an inch, and having a weight of a little more than an ounce, or about one-fiftieth of that of the brain. In the human subject it ends below in a thread which represents in a shrivelled

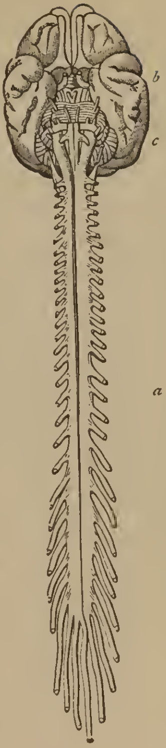


Fig. 21.—Brain and Spinal Cord of a Monkey.

The spinal cord (*a*) is seen to give off nerves symmetrically to each side of the body, while the brain (*b*) forms a mass which is composed of many centres.

condition its continuation in those animals that possess a tail. Above it expands to form the medulla oblongata (opposite *c*, Fig. 21), which crowns the spinal cord like the capital of a pillar. When cut across it is found to be composed of two parts, a grey internal substance and a white external substance; the former is chiefly made up of nerve-cells, the latter of nerve-fibres. The nerve-fibres are so arranged as to form columns, named, from their position, anterior, lateral, and posterior. Some of these fibres connect different parts of the spinal cord with each other, others are sensory, conveying tactile impressions from the skin of the limbs and body upwards to the medulla oblongata and brain; whilst others descend from the brain to the muscles, and serve to convey motor impulses. From the grey substance two groups of nerve-fibres arise, named the anterior nerve-roots (Fig. 22) and the posterior nerve-roots. The latter have a ganglionic enlargement upon them. It is the glory of modern physiology to have ascertained that these two roots differ in function, the anterior nerve-roots being motor, the posterior sensory. This has been ascertained by dividing each root separately, and stimulating by means of electricity the cut surfaces. Supposing, for example, the posterior root (*a*) be divided at the point (*h*), and that part which remains connected with the cord indicated by (*a*) were stimulated, the animal gives indications of

pain by cries, but if the part connected with (*d*) be stimulated, no indications of pain are given. The only conclusion to be drawn from this is, that the root (*a d*) is the channel by which sensory impressions are conducted to the spinal cord, and so upwards to the brain. On the other hand, if the anterior root (*b*) be divided, and the part still remaining in connection with the cord be stimulated, no effects are produced, the animal remains quiet and gives no indications of pain; but if the other part or that which is severed from the cord is stimulated, then, although the animal still continues to give no indications of pain, the muscles of the part to which the root is distributed are violently convulsed. Hence the conclusion has been drawn that the anterior root is the channel by which motor impulses are transmitted to the limbs and body.

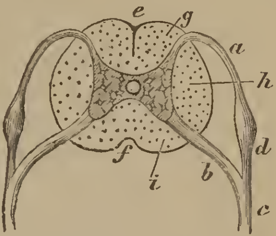


Fig. 22.—Section of Spinal Cord.
The grey matter is the shaded portion in the centre from which the nerves *a* and *b* emanate; *g*, *h*, *i*, the white substance, *g* representing posterior column, *h* the lateral column, and *i* the anterior column; *f*, anterior; *e*, commissure; *b*, anterior or motor root; *a*, posterior or sensory root; ganglion; *c*, mixed nerve, or nerve of mixed sensory and motor endowments.

After a short course the two roots unite, and then form a nerve of mixed endowments · that is to say, a

nerve which contains both motor and sensory fibres. If such a nerve be stimulated, the animal gives signs of pain and its muscles are convulsed, whilst if the nerve be divided irritation of the part still in connection with the cord causes pain, whilst irritation of the distal or severed portion produces muscular contractions. Though so small in bulk, the spinal cord and medulla oblongata are extremely important parts of the nervous system. The grey matter they contain may be regarded as consisting of a chain of numerous nerve-centres coalesced into an elongated mass, which presides over many reflex acts, and especially over those of respiration.

The brain of man is far larger in proportion to the size of the body than that of any other animal, and larger absolutely than that of any other animal, except the whale and the elephant. It is carefully protected by the bones of the skull, and by the membranes which invest it. These are three in number, and are named respectively the dura mater, arachnoid, and the pia mater. It consists of a thin layer of grey substance which, unlike the spinal cord, is situated on the surface, whilst the white substance is within. The latter is formed of nerve-fibres connecting the cells on the surface with the deeper lying parts near the base. The grey matter is composed of cells, and forms a great nervous centre, or rather aggregation of nerve-centres; originally the outer surface is smooth

and uniform, resembling the condition seen in the adult opossum, porcupine, and guinea-pig; but on account of the exigencies of space it becomes in man and in the higher mammals folded upon itself, giving rise to its well-known convoluted aspect.

In proportion to its size the brain receives more blood than any other organ of the body, for four large arteries convey the streams that are ceaselessly pumped into the head from the heart, and break up into so fine and delicate a plexus that the name of "rete mirabile," or wonderful network, has been rightly applied to it. Nor is the quantity of the blood alone remarkable, for even before birth arrangements of the most singular and special kind exist, which have for their principal object that the blood supplied to the brain should be charged with oxygen, and thus that the conditions for its activity should be rendered perfect. Its rudiments are the very first that appear in the long process of development; yet it is the last part of the body to attain its full maturity.

At the lower part or base of the brain is a series of grey masses, which are also nerve-centres. These ganglia, situated at the base of the brain, and the mass of grey matter forming the exterior of the cerebral hemispheres, require to be clearly distinguished from each other. The former are the seat of the consensual operations; that is to say, the sensations derived from the sense of touch

throughout the body, those derived from the eye and other senses are all here received, and give rise to a kind of dim consciousness which can excite appropriate movements of a reflex character.

The grey matter which forms the outer surface of the hemispheres is the seat of true consciousness, of the intellectual processes, and of those impulses which produce voluntary movements.

The hemispheres of the brain appear also to be capable of exerting a restraining or regulating influence over the truly reflex and the instinctive acts. If the hemispheres of the brain be removed from an animal, the body still responds to impressions made on the organs of sense; a loud sound startles the animal; a pinch causes a frog thus mutilated to leap forward, and a bird under similar conditions will follow a candle in an otherwise darkened room. The creature seems to be in a state of dreamy stupor which still admits of movements habitually performed under the influence of certain stimuli to be continued, but though purposive they are mechanical in character, and are pursued even when injury is certain to follow. In man all the higher mental processes, as comparison, judgment, abstract thought, and the affections and emotions generally, are the outcome of the changes which take place in these parts.

It was formerly supposed and it is still held by some

physiologists, that in the performance of any mental effort, as, for example, in the solution of a problem, the brain acts as a whole, and that all the nerve-cells participate in the process. The sensation of general fulness of the head, the throbbing and headache, not limited to any precise spot, which accompany or follow protracted mental exertion, are circumstances favourable to this view. On the other hand, recent observations have supplied strong grounds for believing that particular parts of the brain are endowed with especial functions. Such a special centre presiding over groups of nerve-cells that are almost certainly present, though not specialised, in the lower animals, may be instanced in the centre for speech in man; many animals communicate by voice, and the nerve-centres, the cells and nerve-fibres, and the muscular apparatus of the larynx are all present, but the possession of articulate speech belongs to man alone, and its gradual evolution in the course of ages has had an incalculable influence in enabling men to combine with others in making efforts in common. Below and behind the cerebrum and between the cerebrum and the medulla oblongata is the cerebellum. In structure this organ resembles the cerebrum, presenting an outer much convoluted layer of grey matter, composed chiefly of nerve-cells, and an internal mass of white nerve-fibres. The arrangement of the two is peculiar, and a section of them

is said to show the "arbor vitæ." As in the case of the cerebrum, the cerebellum is developed to an extraordinary extent in man, its size and complexity being proportionate to the variety of the movements of which he is capable; and the opposition of the thumb to the other fingers and the general mechanism of his hand, has, as Sir C. Bell well showed, exerted no slight influence in placing him at the head of the animal creation.

The cerebellum is connected by large masses of nerve-fibres with other chief parts of the central nervous system —with the brain or cerebrum proper above, with the spinal cord below, and with the pons Varolii, and through it with the great sensory ganglia at the base of the brain in front. It is believed to be the organ by means of which the harmonious combination, or as it is generally termed the co-ordination, of muscular movements for definite purposes is effected; for it has been noticed when the cerebellum is affected by injury or by disease that animals are unable to guide their steps in accordance with the impressions they receive from their organs of sense, that they stagger, or even have a tendency to fall backwards.

We now proceed to consider the mode in which the nerve-cells and fibres can be called into play.

Stimuli.

It may be accepted as a general statement that no nerve-cell is capable of acting spontaneously. The processes of nutrition may lead to the storing up of energy, but this can no more be set free without some external influence acting upon the cell than gunpowder will explode without a spark. The liberation of energy by a nerve-cell requires that some excitation in the form of a vibration should be communicated to it, by which the previously unstable compounds it contains may be decomposed and form a more stable arrangement of elements. Such an exciting agent arousing a nerve-cell to activity is termed a *stimulus*. The nature of the vibration may vary. It may consist of the large and coarse vibrations produced by mechanical shock or violence, or the more delicate vibrations which constitute the stimuli of sound, heat, light or electricity, or those subtle changes which are caused by the operation of chemical agents.

In the lower forms of life, as we have seen, all parts of the body respond in a similar manner to every kind of stimulus; but in proportion as the nervous system becomes specialised, particular nerve regions respond only to definite stimuli, one part responding to the stimulus of light, another to that of sound, and another to that of odorous emanations. By still further specialisation, varia-

tions in the kind and degree of these and other stimuli are recognised, until at length a discriminative power can be exercised between the different shades of a colour, the intensity and pitch of sound, and the more delicate qualities of taste and smell. Electricity, even in the highest animals, seems to constitute a stimulus to every kind of nerve, exciting a sensation of light when applied to the eye, of taste when applied to the tongue, and readily inducing contraction of muscle when applied to a motor nerve.

The intensity of the stimulus bears, as a rule, a certain relation to the effects produced, and each sense may thus be said to have a gamut of impressions, slight effects being produced by feeble stimuli, and strong effects by powerful stimuli; but it often happens, that owing to a peculiarly unstable condition of the elements of which the cells are composed, a feeble stimulus may produce an extraordinarily powerful effect. A slight sound which under ordinary circumstances would pass unheeded, may in the dead of night, in a person whose nervous system is rendered more impressionable by exhaustion or fear, produce a shock that is very perceptibly felt through the whole system. In a neuralgic patient, again, a breath of wind will occasion an access of pain, and in various conditions of the system exposure of the eye to a very moderate light causes intense discomfort, which is

rendered manifest, whilst it is only partially relieved by a flood of tears.

The stimulus, whatever may be its nature, may of course act either upon the central nerve-cell, upon the nerve-fibre, or on the end organ of the nerve. At first sight it would appear to be immaterial to which of these three parts it is applied, and no doubt in the most rudimentary conditions of the nerves little or no difference would be perceived by the animal whether this or that part were stimulated; but experiment has shown that in all the higher animals, although the stimulation of the nerve-fibre excites a sensation similar in kind to that which it is accustomed to transmit, yet that all the finer shades or degrees of sensation are lost, and in order that these should be perceived it is necessary that the end organ should be the part stimulated. A good example of this is afforded by the effects of a burn sufficiently severe to destroy the end organs of the skin without entirely abolishing the excitability of the sensory nerves, for it is then observed that all the more delicate modifications of the sense of touch, such as the difference in different bodies of varieties of texture, degree of temperature, and the like, are no longer perceived, but that instead there is a feeling of soreness and pain, when a mechanical or other stimulus is applied to the injured part. So in regard to the eye: whilst our perceptions of colour, form, motion,

and relative position of objects are more or less exclusively obtained from impressions made on the retina, it is certain that stimulation of the optic nerve itself, if the retina were destroyed, would only produce the sensation of a flash of light.

In order that a stimulus may excite a nerve, it must neither be too feeble nor too sudden in its action; and if it continues to operate, it must vary in degree. Thus the skin may be touched so lightly that no vibration is conducted along the nerve to the central cell, and it is therefore unperceived; and similarly so feeble a stimulus may be applied to a motor nerve, that the muscle it supplies will present no contraction. On the other hand, a very rapidly inflicted, even if severe, injury is often painless, and many instances have been recorded of severe cuts received in battle which were not at the moment perceived. No uniform and permanent excitation long continues to act as a stimulus to a nerve-fibre or cell, and indeed if the passage from one degree of intensity of a stimulus to another be exceedingly gradual, no sensation is produced in the case of a sensory nerve, and in the case of a motor nerve no contraction in the muscle. Thus, if the skin be exposed to a temperature gradually and slowly rising, it has been found that animals exhibit no evidence of pain; and similarly with a motor nerve, the rise in intensity of a current applied to the nerve may be

made to take place so uniformly and continuously that no spasm of the muscle occurs. To produce sensation or motion, the stimulus applied to a nerve must be moderately sudden and violent, and if continued must vary in degree. The continuous action of any stimulus produces exhaustion, and before the nerve-fibre and cell can again respond to it, time must elapse in order that the nerve-cell may again store up energy, derived from the materials supplied to it by the blood or other circulating fluid.

The real action of a stimulus upon the nerves is unknown, but there is reason to think that it occasions a wave of chemical change to travel through the nerve. The more unstable the composition of the nerve-fibre and cell the more rapidly will the change be propagated to the nerve-cell by the nerve, and the more sudden and violent the action of the cell. A strong stimulus or the repeated application of the same stimulus causes all the unstable matter in the nerve and in the cell to become converted into stable combinations, and it then ceases to respond to further stimuli, and is said to be exhausted; but if the blood supply be free and sufficient the new combinations are carried away; the cell becomes renewed or reintegrated, and is again susceptible of stimulation. The rapidity of this renewal is well shown by the heart, where the stimulus of the blood entering its chambers

induces a series of rhythmical contractions which number nearly 80 in the minute and may be continued for a century.

Our knowledge of the mode in which impulses are conducted through nerves is imperfect. The singular analogy they present in structure to a telegraph wire, which has already been pointed out, and the apparent instantaneity with which the impulses of the will are conducted to the most remote parts of the system, or arrive at the brain from the periphery, have led many to adopt the hypothesis that nerve force is only a modification of electricity, and is subject to the same laws. Many reasons could, however, be adduced to show that electricity and the nervous force are not identical. When we will to move a finger or toe, the movement seems to be coetaneous with the volition; and when the finger is pricked with a needle, the contact of the point and the perception of that contact seem to be separated by no appreciable interval of time. In both cases the impulse must traverse the whole length of the nerves between the brain and the extremity, and yet no time seems to be lost. The exact methods of modern research, however, have enabled the physiologist to estimate the rapidity with which impulses travel in either direction, not only in the exposed nerves of animals, but even in man. The principle of the method by which the rapidity of trans-

mission of motor impulses is determined consists in attaching to the end of a finger, or to the extremity (*a*) of a muscle, a pen or style which is just allowed to rest on a rapidly revolving blackened disk. Now, so long as the muscle is quiescent the pen describes only a fine circular line on the disk, but on stimulation of the nerve the muscle contracts, and the pen suddenly starts towards the periphery of the disk, describing an oblique line. The

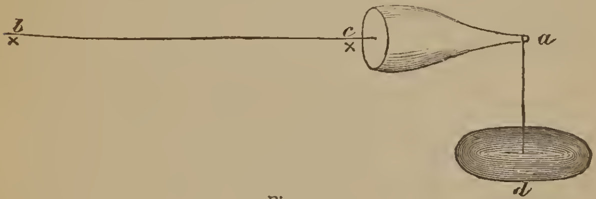


Fig. 23.

instant of the application of the shock is registered on the same disk, but if this shock have been applied at (*b*) in the first instance, and in a second experiment at (*c*), a distinctly longer period will be found to have elapsed before the muscle begins to contract in the former than in the latter instance. This can only be due to the time that is lost in the stimulus passing from (*b*) to (*c*), and the difference between the two periods will give the rate of transmission of the motor impulses along the nerve. The

rate of transmission of sensory impulses may be estimated in a similar way, and the general result at which experimenters have arrived is that nerve impulses travel at the rate of about 100 feet a second. In a large animal therefore, as a whale or a python, a whole second may elapse before an injury to the tail is recognised by the head, and another second before the muscles necessary for moving it can be brought into play. This in itself establishes an important difference between nerve force and electricity, the latter traversing 200,000 miles in the same time through copper wire.

The facility with which nerves conduct depends upon the freedom with which blood circulates through them, or in other words, on the perfection with which their nutrition is effected. When the fingers are very cold their sensibility is impaired, and it becomes difficult to write or draw, or dress, or to perform any of those slight but delicate movements which are required in every-day life. We say we cannot feel that the fingers or toes are numb, and the circulation must be established for some time before the parts quite recover their natural acuteness of perception and fine adjustment of movement. Advantage is sometimes taken of this effect of cold in the performance of surgical operations, and when the wound to be inflicted is slight and superficial, all pain can be avoided by cooling the parts down to the freezing point,

which may be accomplished by directing upon them for a short time a fine spray of ether, which in evaporation abstracts much heat from the part. The importance of healthy circulation through the parts may be shown in another way—as by winding an india-rubber band tightly round the middle of one of the fingers; the tip soon becomes purple, owing to the obstruction caused by the bandage to the return of the venous blood; and it will be found that if the sensibility of the swollen part be not quite lost, it is at least considerably impaired. A very tight pair of boots similarly deadens or numbs the sensibility of the skin of the toes.

Reflex Actions.

We have now learned that different nerve cells differ in their functions, some perceiving impressions or being sensory in function, whilst from others impulses issue which cause a muscle to contract or a gland to secrete. In the former case the impression travels along a nerve-fibre, which is hence called a sensory nerve, or sometimes an afferent or centripetally conducting nerve, and in the latter case the impulse is transmitted along a motor nerve, also termed an efferent or centrifugally conducting nerve. We have further seen that both kinds of nerve-cells are called into action by a stimulus, which may either act upon the

nerve-cell itself, or upon the end organ of the nerve-fibre in connection with it. Now when the impression made by any stimulus on an end organ, say of one of the fibres of the eye, ear, or skin, is conducted by an afferent nerve to a sensory nerve-cell, and is transmitted from this to a motor nerve-cell, inducing such a change in it that it sets free an impulse which causes a muscle to contract, or a gland to secrete, a *reflex* act is said to occur. It is not necessary, however, that the mind should be conscious of the sensation which occasions the act.

A good example of a reflex act, unaccompanied by sensation of any kind, is met with in the case of the heart. In this instance the stimulus is the contact of blood with the membrane lining the cavities of the heart; the stimulus is conducted by the cardiac nerves to the sensory ganglia in the walls of the heart; and from these to motor ganglia, the impulses from which cause contraction of the heart. If there were no stimulus conveyed to the ganglion cells no motor impulse would be liberated, for, as already stated, the cells never start or inaugurate movements of themselves, or automatically.

Another good example of reflex action not accompanied by sensation is exhibited in the ordinary acts of respiration. A healthy person breathes about sixteen times in a minute, the breathing consisting in alternate acts of inspiration and expiration. These are

performed entirely independently of the will, for however completely our minds may be absorbed in thought, and even in the deepest sleep or under the influence of anæsthetics, the respiratory acts are alternately performed with great regularity. We can at will hasten them or retard them, we can breathe for a short time at the rate of a hundred times a minute, or at the rate of once a minute, but we cannot stop them for more than about a minute and a half without the desire to breathe becoming so imperious as to master the strongest resolution; and no man has ever been known to commit suicide by voluntarily restraining his breathing. How is this process conducted?

By a reflex act. If breathing be arrested, the blood and the air in the lungs become after a very few seconds charged with carbonic acid gas, which acts as a powerful stimulus to the nerve distributed to the lung, named the pneumo-gastric. The impressions made on this nerve are conducted to the upper part of the spinal cord, and originate impulses which are *reflected* back through the phrenic nerve to the diaphragm, and through the intercostal nerves to the muscles between the ribs, the contraction of which enlarges the chest and leads to inspiration. We have just seen that although the due performance of respiration is essential to the maintenance of life, yet that the rapidity and the rhythm of the acts are under the

control of the will. This is necessary in order that the respiratory acts should be duly subservient to the important faculty of speech, and it shows that the will may exert a very disturbing influence on the phenomena of reflex action.

Examples of reflex acts accompanied by sensation may be drawn from the eye, and are familiar to all. If the pupil of the eye of a person sitting in a dull light be examined, it will be found to be large and stationary; but if a candle be brought near to the eye the pupil becomes smaller, so that less light is admitted. On removing the candle, the pupil again dilates. The variations in the size of the pupil here observed are reflex acts. They are not under the dominion of the will, but they require that the groups of nerve-cells in which the optic nerves terminate, or the optic nerve-centre, should be sensitive to light; and the series of events is that the light of the candle falling on the retina acts as a stimulus, producing an impression which is conducted to the optic centre. The cells forming this centre then originate an impulse which is transferred to the third nerve, which is a motor nerve, and from thence travels down to the muscular fibres of the iris, by the contraction of which the pupil is closed. On the other hand, when the candle is withdrawn, the optic and third nerves are no longer stimulated, and the muscle which diminishes the size of

the pupil ceases to contract, whilst the opposing or dilating muscle which is supplied by the sympathetic nerve comes into play. The closure of the eyelids which occurs when a blow is aimed at them is a similar instance of reflex action accompanied by sensation, though the nervous arc is not the same, the motor impulse travelling through the seventh instead of the third pair of cerebral nerves.

Reflex acts may be best seen in animals that have been decapitated, and the slowness with which the body deprived of the head dies in frogs and turtles cause these animals to be most frequently employed for the purposes of demonstration. The same phenomena may, however, sometimes be seen in man, for it occasionally happens as the result of an accident, as of the falling of a mass of earth on an excavator, or by injury caused by shot, that the back is broken, and the spinal cord is crushed or divided. The sufferer is instantly rendered incapable of standing or walking, and finds himself to be entirely deprived of voluntary control over the muscles of his legs. To him they are dead, foreign things; the most violent irritants—corrosive acids, a sharp cut, the application of a red-hot iron—arouse no sensation, cause no pain, nor will the apprehension of instant death, with the knowledge that life depends on a leap, enable the slightest exertion to be made with them. The legs are said to be

paralysed, and the paralysis is complete both as regards sensation and motion. Yet they are not dead, and they will still respond in a certain way to stimuli appropriately applied. If the soles of the feet be tickled, or still better, if a rather hot spoon be applied to them, they are instantly drawn up and away from the stimulus. The movements, although not in any way under the control of the will, yet are to a certain extent purposive. They constitute good instances of reflex actions without sensation, and the mechanism of the process seems to be that the grey matter of that part of the spinal cord which is situated below the injury contains nerve ganglia which preside over the movements of the legs; under ordinary circumstances, these ganglia are excited by impulses coming down from the brain,—voluntary impulses, as they are termed; but they may also be excited by sensory impressions derived from the surface of the skin. When the influence of the brain is cut off the latter stimuli continue to act; and hence the movements which are observed. In cold-blooded animals phenomena of a similar kind are very distinct, and the movements are so purposive, or have so definite an end and aim in view, that many physiologists have been led to maintain that the seat of consciousness is not, as in man, limited to the brain, but is distributed throughout the whole length of the spinal cord. For if the head of a frog be cut off

with intent to kill it and the body be suspended from a peg, and a camel-hair pencil dipped in a little acetic acid be applied to any part of the flank, the leg of the same side is immediately drawn up, and an effort is made on the part of the animal to brush away the acid with the hind foot. The action is a purposive one, and is highly suggestive. As the animal is destitute of a head, it cannot be supposed that the will has anything to do with the action. Yet it involves the action of many muscles, and the curious point is that the action of these muscles effects such a movement of the paw as to direct it to the right spot. It is a true reflex action, and the chain of events is that the stinging sensation caused by the acetic acid is conducted to the spinal cord by one or more fibres represented by *s* in A, Fig. 24; here it excites one or several of the cells of the grey substance to action, and an impulse is immediately generated which is transmitted to motor cells and then along the motor nerves M to the muscles of the thigh, but evidently not to all of them, because their contraction would then be general, spasmodic, and purposeless, but along certain tracts only, which the animal before decapitation was accustomed to use in performing the same act.

But more information can be gained from the same experiment if the acid be applied several times, or in a more concentrated condition, so that it constitutes a

stronger stimulus. A new phenomenon occurs, the reflex act is no longer limited to the leg of the same side, but the other leg or foot makes an effort to brush away the offending body. Thus it would seem that the stronger

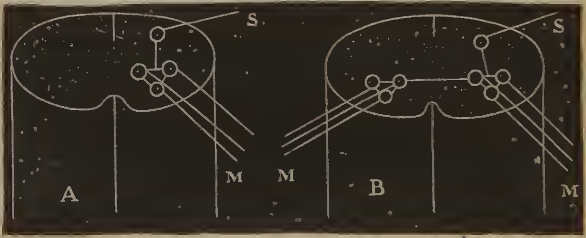


Fig. 24.

stimulus so powerfully excites the sensory nerves that the impression passes across to the opposite side of the spinal cord and thus excites the opposite motor nerves (B, Fig. 24).

The most reasonable explanation of these and similar phenomena appears to be, that the spinal cord contains certain ganglia or groups of nerve-cells, which when stimulated cause several muscles to contract in an associated manner. Under all ordinary circumstances, and before the animal is decapitated, the stimulus to this movement is any irritation of the skin; the sensory

impression thus produced is conducted through the spinal cord to the brain, and there leads to a conscious effort being made by the animal, which travelling downwards excites the muscles in question to act together in harmony. When, however, the same stimulus is applied to the skin in a decapitated animal, the sensory impression can no longer travel upwards to the head, but is deflected to the group of ganglionic cells of its own side, or if strong, to the cells of both sides, which as before bring into harmonious and purposive action the muscles required to produce the movements formerly directed by the brain. We shall presently see how secretion may take place as the result of reflex action.

Relation of the Nervous System to Digestion.

The first stage of the process of digestion, consisting in the mastication or comminution of the food, is purely voluntary, though the frequency with which it is performed causes it to become an habitual or secondary automatic action. In the mouth the food is mingled with saliva, which is poured forth from the salivary glands by a reflex act, and when it has become sufficiently moistened a portion of convenient size is pressed by the tongue to the back part of the oral cavity. Voluntary effort now ceases, and is succeeded by a singularly complex and delicate but

perfectly effective series of movements, collectively termed the act of "deglutition." In this act, the sensation caused by the bolus of food excites two sets of muscles, one of which, the pharyngeal, seize and contract upon the morsel and guide it into the œsophagus; whilst the other set, the laryngeal muscles, raise the larynx, and prevent the entrance of the food into the windpipe. Having passed this critical point, where if the mass took a wrong direction suffocation would result, it is rapidly propelled along the œsophagus by a wave of the muscular contraction into the stomach. Up to the moment when it enters the œsophagus we still possess some power over its movements, and a peculiarly nauseous body can with an effort be expelled; but as soon as it is fairly grasped by the muscular fibres of the œsophagus, it has passed beyond the reach of the will and must travel forward to the stomach, exciting, unless its temperature is extremely high or low, little or no sensation. In the stomach the food is churned, mingled with gastric juice, and is partly dissolved and partly absorbed. The stomach is a muscular sac, and its movements are essentially due to the action of nerve ganglia distributed through its walls, and in part also to the pneumo-gastric nerves, both acting in a reflex manner. The secretion of gastric juice is poured forth from thousands of minute pits in the walls of the stomach in response to the stimulus of the food acting on the free

terminations of sympathetic nerves. After due digestion has taken place, the food mingled with saliva and gastric juice, and now called chyme, flows through the pyloric gate of the stomach, which previously tightly closed, now dilates sufficiently to allow it to pass, so that about four hours after food has been taken the stomach has expelled the whole of its contents and becomes quiescent. The small intestine now takes up the action, the stimulus of the acid chyme immediately stimulates nerve-fibres which conduct the impression to nerve-centres, partly contained in the medulla oblongata and partly in the sympathetic system of the abdomen, and which excite a flow of bile and pancreatic juice and of intestinal fluid. The transit of the food through the alimentary canal is only a repetition of its course in the stomach. No conscious sensation is experienced, but at each point the materials stimulate afferent nerve-fibres which conduct impressions to ganglia from which motor impulses emanate that cause uniform contractions of the muscular walls of the intestines. These regular and co-ordinated movements constitute the peristaltic contractions of the intestines. The remains of the digested food, collecting in the lower part of the larger intestine, are discharged at intervals by an effort of the will excited by sensations which are once more felt.

Relation of the Nervous System to the Circulation.

The blush of surprise or of pleasure, the pallor of fear or of pain, and the throbbing of the heart that is experienced when the mind is excited by various emotions, constitute sufficient evidence of the influence that the nervous system exerts over the circulation, and are phenomena that are worthy of careful consideration.

At first sight scarcely any organ seems to be more independent of the nervous system than the heart. The heart of a frog, a turtle, or of a fish, may be excised, and if kept moist by immersing it in a little serum or fluid containing albumen it will continue to beat for hours with a measured and rhythmical action. Even when under these unnatural conditions its action has begun to flag, it will, if stimulated by the prick of a needle or a spark from an electrical machine, recommence to beat for a time, though no doubt the pulsations succeed each other more slowly, then become weak and irregular, and finally cease. The reason of this is to be found in the fact that the heart has a nervous mechanism of its own; it has its own afferent fibres, sensory and motor ganglia or centres, and efferent or motor nerves by the action of which its movements are maintained automatically even when it is altogether isolated; whilst still a part of the living

body, however, this nervous system, which is proper and peculiar to the heart, is connected with the cerebro-spinal and with the sympathetic nervous systems, by both of which it is influenced. The sympathetic nervous system appears to supply accelerating impulses, whilst the cerebro-spinal system is capable of exerting a restraining, retarding, or, as it is sometimes called, an inhibitory influence. So powerful is this action that a violent emotion has been known to arrest suddenly and permanently the movements of the heart, and it has been ascertained by experiment that the channel through which this influence is exerted is the great vagus or pneumo-gastric nerve, which descends from the medulla oblongata to the lungs, heart and stomach. A few years ago a distinguished physician suffered from the growth of tumour in the neck, and observed that if he pressed on the tumour in such a way as to compress the pneumogastric nerve beneath it, the movements of the heart became feeble, and could even be entirely arrested. In a few moments its action recommenced, but it cannot be denied that such an experiment was fraught with the utmost danger to life. It is possible to produce the same effect upon a healthy man by direct pressure on the nerve in question. One instance, and but one, is known in which a man was examined by a careful observer and ascertained to possess a voluntary power of arresting the

action of the heart. This gentleman actually stopped for some minutes the beats of his heart, and when alarm was created by his apparent death, caused or permitted its action to recommence. It is right to add, however, that a repetition of the experiment, against the earnest advice of his friends, terminated fatally.

But the emotions exert a familiar and well-marked influence on the action of the heart. For example: The paleness of fear is in part, though as we shall immediately see not altogether, due to the effects of that emotion on the heart. The impulses excited by the emotion of fear travel down the pneumo-gastric nerves, and restrain the action of the heart, which then beats weakly and irregularly, or may be altogether brought to a standstill. But apart from this influence on the heart the blood-vessels also respond to the action of the nervous system. The blood-vessels are channels which convey the blood to all parts of the body, that each may receive the nutritive substances required to maintain it in health, and to meet the varying requirements of each region; a great part of the thickness of these walls consists of muscular tissue, which yields, expands, or dilates when much blood is required, and contract when little is wanted. The control of these variations is vested in two sets of ganglia, one of which is situated in the spinal cord, whilst the others are either imbedded in the walls of the vessels or

lie in close proximity to them. It is known that a very important centre is situated in the upper part of the spinal cord, and in the medulla oblongata, which is named the vaso-motor centre, because when stimulated it causes all the arteries in the body to contract, whilst its destruction is followed by their dilatation. Under ordinary circumstances it is believed to exert a gentle and uniform contracting influence on the vessels generally, keeping up that tonic contraction which is characteristic of health. The nerves emanating from this centre run down the spinal cord, and issuing with the spinal nerves join the sympathetic system, and from thence pass to the vessels. They are for the most part small and inconspicuous, and are so mingled with the ordinary motor and sensory nerves that their course is difficult to trace, but in one instance at least they form a large, distinct, and highly important trunk. This trunk is named the splanchnic nerve; it is formed by the union of the branches from several of the sympathetic ganglia in the chest. It descends to be distributed to the blood-vessels of the intestines. The use it subserves is obvious. No part of the body differs so much in its requirement of blood as the alimentary canal. During fasting the circulation of blood through the blood-vessels of the stomach and intestines is comparatively sluggish, but no sooner is food introduced into the stomach and the

process of digestion commences, than a sudden rush of blood takes place to all the organs engaged in the digestion, absorption and assimilation of food. The blood-vessels dilate, every part assumes a rosy hue, the whole glandular apparatus of the walls of the stomach and intestines—the pancreas, the liver and the spleen—all swell, and actively discharge their functions. The absolute quantity of blood distributed to and contained in these parts is enormously increased, and hence we may remark in passing, the propriety of rest both of mind and body during digestion, for the blood is called away from all other parts. After the lapse of an hour or two the intestinal excitement ceases, and blood is once more driven out by the contraction of the vessels of the abdomen into the system at large. These immense variations are controlled and regulated by the splanchnic or vaso-motor nerves, and it has been shown by experiment that if these nerves are divided or paralysed, all the blood-vessels of the abdominal organs relax and become engorged with blood; whilst if they are stimulated the muscular walls of the blood-vessels contract upon their contents, and squeezing out the blood they contain render the viscera pale and anæmic.

But quite apart from the action of the great central ganglia of the nervous system there is reason to believe that the vessels of every small tract of the skin or other

organ are under the governance of local ganglia, which regulate the supply of blood to that particular region or territory. This may be shown in a very simple way by drawing the point of a pencil with moderate pressure over the fair skin of the forearm or neck. The line after the lapse of a second or two appears white, and remains so for some time, but is slowly replaced by a rosy blush which extends for some distance from the parts touched. The explanation of this is that the stimulus of the pencil point excites the local ganglia imbedded in or in close proximity to the walls of the blood-vessels, and a motor impulse is transmitted to the vessels causing them to contract. They therefore transmit less blood and the line appears white, but the muscular walls soon become exhausted, and ceasing to contract yield to the ordinary pressure of the blood. Their increased width allows more blood to enter, and the part then assumes the pink tint of congestion, which again gradually disappears as the vessels recover their temporarily diminished tone.

The effects of alcohol are very suggestive in regard to the action of the nervous system upon the circulation. In moderate quantities, alcohol stimulates the nervous centres, its action however being followed by a corresponding degree of exhaustion. In larger quantities its stimulant effect is short, whilst it induces more or less

complete paralysis of the nervous system. The flow of conversation, the increased mental activity, the capability of continuing bodily effort when fatigue is already experienced that occur after its moderate use, indicate its stimulant effects. These indeed are the results of its stimulating influence on the nervous system of the heart, causing that organ to beat with increased force and to drive more blood through the vessels of the brain and spinal cord, and if only a moderate quantity be taken the after-effects are not particularly remarked, though some lassitude and indisposition to work are usually felt. If however an excess be consumed, as is but too frequently done in many a jovial evening, the central as well as the peripheral local ganglia are exhausted, and the smaller vessels of the skin and other parts remain widely dilated, whilst the energy of the heart is greatly diminished. The bad or even fatal effects of exposure to severe cold under these circumstances are well known and are easily intelligible, for the vessels of the skin instead of contracting and so forming a non-conducting layer, as they should do when exposed to cold, are fully expanded, and thus allow a large portion of blood to lose heat by radiation and conduction, and the temperature of the whole body is thus seriously lowered. The popular remedy of a cold douche to induce recovery of consciousness is perfectly rational, for the shock contracts the smaller vessels and

drives the blood into the central organs again. The mechanism of blushing is not easily explained, and there is some difference of opinion amongst the best physiologists on the point. Clearly the change of colour is due to the entrance of more blood into the vessels, but this may arise from several causes. A hasty thinker might say that the emotion liberated a nervous impulse, causing the heart to beat more powerfully for a few strokes, thus driving more blood into the vessels, and distending the capillaries; but the immediate reply is that if such were the cause the blush should extend over the whole body, whereas it is well known to be limited to the face and neck. But again it might be due to an active dilatation of the blood-vessels, so that more blood is admitted into them, and the only objection to this theory is that it is difficult to explain how a nervous impulse can cause the muscular fibres which surround the blood-vessels to elongate as they must necessarily do if the vessels widen. The view most generally adopted is that the nervous impulse is of such a nature as to cause relaxation, not active elongation of the muscular fibres; such impulses are said to be "inhibitory," or "restraining," because they prevent contraction and favour relaxation. Diagrammatically the different views might thus be shown. In Fig. 25, the ordinary state of things is represented. The natural

flow of blood through the artery produces impressions which are carried up to the sensory cell (*s*) and by it transmitted to the motor cell (*m*), from which motor impulses emanate which act on the muscles in the arterial wall and maintain it in a permanent state of moderate contraction.

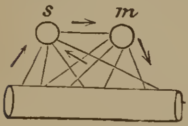


Fig. 25.

But if some stimulus be applied to the wall of the vessel, as the prick of a needle, say at (*p*, Fig. 26), the effect of the stimulus travels up to the sensory cell (*s*) and thence to the motor cell (*m*), but exciting them more strongly than before, a powerful impulse is originated, which, descending to the wall of the vessel, causes it to contract and admit

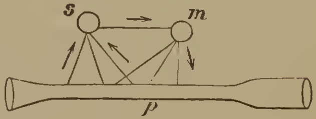


Fig. 26.

less blood, and the part becomes pale; such paleness may last for a few seconds only, as is usually the case, or for much longer periods, the contraction gradually giving place to dilatation.

But in blushing the dilatation of the vessel is sudden, and is not preceded by contraction, and the two explanations of it that have been given are, that as in Fig. 27 there is a controlling or inhibiting cell (*c*), which is not ordinarily called into action, but which being excited by an emotion at once acts on the motor cell (*b*), preventing it from originating motor impulses, and as a result the muscular coat yields to the ordinary pressure of the blood, and the cheeks or other parts assume the rosy tint under consideration. The second explanation is, that connected with the sensory cell (*s*) is a second motor cell (*d*) which when excited through (*s*) does not originate contracting but *dilating* motor impulses, causing the muscular fibres to elongate and thus enlarge the calibre of the vessels.

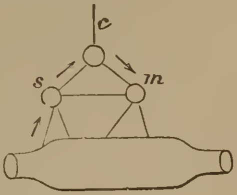
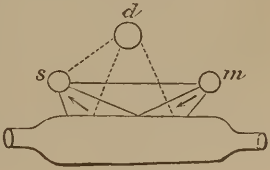


Fig. 27.



ig. 28.

The influence of the Nervous System on the Respiration.

The movements of respiration are required to introduce oxygen into the blood, and to effect the removal of the carbonic acid which proceeds from the decomposition of the tissues. If either of these two processes be interrupted for more than a minute or two death results, and it is hence of the utmost importance that the acts should be conducted automatically; and so effective are the arrangements by which they are accomplished that they continue to be regularly performed when our minds are altogether abstracted from our bodily movements and sensations, in the deepest reverie or in the profoundest sleep; and so powerful are the sensations which prompt us to breathe that no man, however determined, has ever yet been able to deprive himself of life by suspension of the respiration, since after the will has ceased to act, and incipient asphyxia has commenced, the automatic power of the respiratory nervous centres reasserts its supremacy, and the rhythmical movements of breathing again take place. Yet it is requisite that the respiratory system should be under the influence of the will, that we should be able to "hold our breath," if only for a few seconds, and to fix the chest when any great effort has to be made; whilst some control is required in

order that the voice should be properly exerted and the emotions expressed. It is clear then that the movements of respiration stand in a double relation to the nervous system; on the one hand, their continuance is provided for by mechanical arrangements which are outside or independent of the will; and on the other hand, their order, rhythm or relative duration is subject to the will. Each of these relations admit of explanation.

The automatic part of the respiratory movements is one of the best examples of reflex movement without sensation with which we are acquainted. It involves, as has been pointed out in the section on Reflex Action, three separate organs—a sensory nerve, a nerve-centre, and a motor nerve. The sensory nerve is the great pneumo-gastric nerve, the fibres of which are freely distributed to the lungs, and the blood, charged with carbonic acid gas, called venous or black blood, which is driven to the lungs by the right heart, is the stimulus; the impression is conducted along the pneumo-gastric nerve (Pn), up to the medulla oblongata (M O). Here it is reflected, and an impulse is transmitted through the spinal cord till it reaches the phrenic nerves (Ph), by which it is conducted to the diaphragm (D), which immediately contracts and descending enlarges the cavity of the chest, as shown by the dotted lines. The lungs follow this movement, and air containing the vivifying

oxygen rushes in through the trachea or windpipe (T), and the act of inspiration is effected. But as soon as the air enters the lungs the blood takes up the oxygen and frees itself of the carbonic acid gas it contains, in accordance with the law of the diffusion of gases, and it now ceases to be a stimulus to the branches of the pneumo-gastric nerves; no stimulus therefore is conducted to the medulla oblongata, and consequently no impulse is directed through the phrenic nerve to the diaphragm, which accordingly relaxes; the elasticity of the chest-walls and of the lungs themselves comes into play; the air, which has lost part of its oxygen and acquired a certain percentage of carbonic acid, is expelled, and the act of expiration is effected. Thus there is a ceaseless ebb and flow of air from and to the lungs, by which the aëration of the blood is accomplished. In the foregoing remarks the diaphragm has alone been alluded to as the muscle of inspiration, for the sake of simplicity; but in reality other muscles, as those extending between the ribs, and named the intercostals, aid in both the movements of expiration and of inspiration, and their value and importance is seen when-

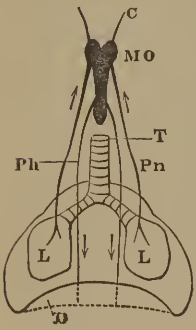


Fig. 29.

ever the respiratory movements are rendered difficult or require to be performed with unusual vigour, as in violent exertion, or in such diseases as asthma. The study of the effects of disease in man and of experiments in animals has supplied much important information in regard to the relations of the nervous system to the respiration. Let us note one or two of the most remarkable facts.

Suppose from disease, as the growth of a tumour, or by an accident, as a bullet, or as the result of an operation, the pneumo-gastric nerves, which conduct the sensory impressions leading to inspiration, were divided or were so compressed as to be rendered incapable of performing their function, would respiration cease? At first sight it might be thought that this result would follow, but experience has shown that this is not the case. In animals in which both nerves have been suddenly divided, a remarkable change in the rhythm of the movements is observed; instead of alternating one with the other at a uniform and definite rate per minute, the act of inspiration is sharp, sudden and short, and is immediately followed by a short expiration, succeeded by a long pause; then the movements of inspiration and expiration are repeated, and again there is a long pause, and so on. Now what explanation can be given of the continuance of the respiratory acts when the sensory stimulus is intercepted? It

is difficult to speak positively, but it is believed to be due to the direct action of the venous blood circulating in the body upon the respiratory centre in the medulla oblongata. The stimulus, represented by the venous condition of the blood or amount of carbonic acid gas it contains, or perhaps the deficiency of oxygen, rises to such a pitch that it causes an explosion, so to speak, of nervous energy in the medulla oblongata, and the impulse liberated is transmitted along the usual channels to the diaphragm and other muscles, and a sudden and powerful inspiration is the result. In the higher animals and man death rapidly follows division or compression of both pneumo-gastrics, but in the lower vertebrata, as in the frog, in which respiration is largely effected through the skin, the results are much less serious.

It has been stated that it was important the respiratory acts should be in part under the influence of the will. In all violent muscular exertions, as in lifting heavy weights or pulling at an oar, it is requisite that the chest should be fixed, since it then constitutes a firm point of support from which the muscles of the abdomen and those passing to the limbs may act. This is accomplished by a strong voluntary effort of inspiration, the impulse descending from the brain through fibres represented by *c*, Fig. 29, to the spinal cord, and then through the phrenic nerves to the diaphragm (D), which assumes the position

represented by the dotted line. In this position it may be retained for a minute or more whilst the effort is made, and until the oxygen is exhausted, when the desire for removal of the air becomes uncontrollable, and expiration, followed rapidly by deep inspiration, occurs.

The actions of sighing, sobbing, laughing and crying, are all results of the interference of the nervous system, excited by emotional or by voluntary impulses, with the normal and regular performance of the respiratory acts.

The relation of the Nervous System to the Secretions.

The secretions are fluids secreted by glands which, when discharged, serve some further purpose in the economy, and in this respect differ from excretions which, though formed by glands, are eliminated from the body as waste products. The definition is not quite accurate, because one fluid, the milk, which is properly regarded as a secretion, is of no further service to the animal producing it, though it serves as food to the young; whilst another, the lachrymal secretion, is truly a secretion when it is discharged to wash away a particle of dust that has lodged in the eye, whilst it is an excretion when it is secreted in response to a mental operation. Speaking generally, however, secretions are formed by glands, and are for the

most part discharged into the alimentary canal. The best examples that can be given are those of the salivary glands and kidneys, the pancreas and the liver, and it is interesting to note the relations that exist between their functional activity and the nervous system.

The accompanying little drawing exhibits the essential parts of a gland. It will be seen to consist of a thin membrane, called the basement membrane (*b m*), on the outside of which is a capillary blood-vessel (*c*), and which is lined internally by a layer of gland-cells, (*g c*). The secretion which is formed by the gland-cells from the blood traversing the blood-vessel is carried off by the duct of the gland (*d*).

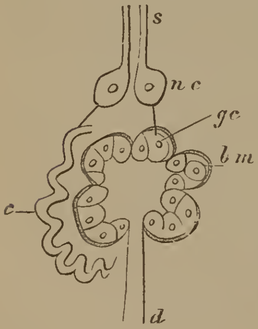


Fig 30.

Now, if we imagine the blood flowing at a uniform rate through the blood-vessel, and the cells constantly drawing material from the current of blood, and after elaborating it in their interior discharging it into the duct, it is clear that the flow of the secretion will also be uniform and equable. But the most superficial observation shows that the secretions are poured forth in varying amount. The quantity of saliva secreted

under ordinary circumstances is small, sufficient only to keep the mouth moist, and to facilitate speech, but as soon as food is introduced an immense quantity is poured forth. In the horse, for example, where it has been weighed, a quantity of saliva equal to one half of the whole weight of the food swallowed is secreted. The question arises, what are the circumstances which lead to this variation in the quantity secreted? Experiment has shown that there is in all instances a reflex action taking place through the agency of the nervous system. In connection with every gland is a nerve-centre, which, when reduced to its simplest anatomical elements, consists of a sensory and a motor nerve-cell. The former is connected with some sensory surface as the tongue, by means of a nerve-fibre, which we may call the sensory nerve-fibre. If this nerve be stimulated, the secreto-motory nerve-cell is excited, which in turn stimulates the gland, causing it to secrete. The exact mechanism of this is still a matter of doubt—some believing that the nerve issuing from the motor cell and passing to the gland, through which the influence is conveyed, or the secreto-motor nerve of the gland, terminates in the very cells of the gland itself (*s*, *nc*, *gc*, Fig. 30.), and hence that the action of the nerve on the gland is direct and immediate; whilst others hold that the nerve terminates as shown on the opposite side of the Fig. in the blood-vessels, and either directly, or by an indirect action, which has been explained in speaking

of "nervous inhibition," leads to their dilatation and to an increased flow of blood through them, and hence to increased activity of the cells and augmented secretion. The arguments on both sides would require for their exposition more space than is here at disposal, but the main fact is certain, that the glands are both excited to secrete when the secretion is required and prevented from secreting when not required through the agency of the nervous system.

The nervous centre of a gland may be excited by impressions coming from many different sources. Thus in the case of the lachrymal gland, its secretion may be induced by physical causes, as by joy and grief, or by an impression made upon the eye (optic nerve), as on looking at the sun, or by pain, especially when that pain is conveyed through the fifth nerve as in tic, or by tickling the skin of the face. It may, on the other hand, be inhibited by various emotions, as by fear or anxiety, a familiar example of which is in the Indian method of detecting a thief, the suspected persons being made to chew rice for a minute or two, and then eject it from the mouth,—the person whose bolus is the driest is regarded as guilty.

Evidence similar in its nature to that which has just been given might be adduced to show that the nervous system exerts a distinct influence upon the production of

animal heat, and, though this has been less certainly ascertained, upon the nutrition of the several organs and tissues of the body. But it is unnecessary to enter into any details upon these points.

Of the higher functions of the Nervous System.

We have now acquired a knowledge of the nature of reflex acts, and have shown that they are very constant and fixed in their nature, admitting of little variation or change; hence they preside over and maintain the chief functions of life, as the respiration of the air and the circulation of the blood, with all the more important processes of secretion. In these acts no true consciousness is involved. We must admit that the centres have feeling or sensation, but it is not materially different from that which appears to exist in many plants. The legs of a man whose back has been broken by a fall will be drawn up in response to stimuli applied to the sole, without the least knowledge or perception of the irritation, nor any effort to move the leg on his part. A heart altogether removed from the body will continue to contract for hours if immersed in blood. In the former case the reflex centre is situated in the spinal cord, for if this be destroyed no further reflex movements can be produced; in the latter case it is clearly owing to impulses emana-

ting from the nerve ganglia in the walls of the heart itself, for if these ganglia be destroyed the movements at once cease. Such movements do not apparently differ from those of the sensitive plant, or of the leaves, stamens, roots and stems of many plants, when excited by appropriate stimuli. We must suppose that there is a definite arrangement of organic elements in virtue of which a molecular change is transmitted from particle to particle till the effect is produced.

As with the sense of touch to which the excito-motor actions performed through the agency of the spinal cord are referable, so it is with the other senses of hearing, smell, taste and vision. The centres of these senses consist of groups of cells situated at the base of the brain, and the impressions made upon them by external agents excite many reflex acts. Such acts or movements are termed consensual, sensori-motor or instinctive. Good examples of them in man may be seen in the start occasioned by a loud and unexpected sound, and the closure of the lids that occurs when the eyes are suddenly exposed to a dazzling light. But their most characteristic expression is found in the instinctive acts of the lower animals, and especially in the higher forms of the Articulata, as in bees and ants. The instincts of these creatures have sometimes been termed compound reflex actions, and they appear to be the outcome of a special

arrangement of the nervous apparatus, whereby certain acts are performed as the result of particular stimuli being applied to the organs of sense. They are tendencies to action which have been engrained in the organisation of the animal by the constant or frequent performance of the same action by its ancestors for an indefinite period. Hence they have been described as the inherited habit of generations.

The instinctive acts of an animal resemble the reflex acts in being performed with little or no example or instruction, and in being so well adapted to the end in view that little is left for reason to modify or improve; but they differ from reasoning acts in the circumstance that they continue to be performed uselessly or absurdly under changed conditions, as when a tame beaver builds a dam of the furniture in a room. It is this indifference to circumstances and to consequences that practically distinguishes instinctive from purely ratiocinative mental processes. An instinctive act is performed not because the animal foresees the result, or sees in the act any special fitness for the purpose required, but in obedience to some internal or external stimulus which excites or sets in motion certain groups of cells, which then act in a reflex manner.

It is a remarkable fact that all actions which are frequently repeated, though they may at first require

voluntary effort and attention, become more and more easily performed, the nervous structures responding more readily and perfectly to the demands made upon it. And this holds good not only for the individual but for its descendants, who inherit to some extent the modification acquired by the parent. An instance of such habitual or secondarily automatic series of movements may be observed in locomotion. The act of walking requires the harmonious co-operation of many muscles, and in the case of man is learnt only slowly and with difficulty; but in course of time the nerve-centres implicated become organised to act in an orderly and purposive manner, and it is only requisite for the will to start the process in order that all the movements should be performed regularly and definitively without further attention being directed to it. That there is a certain tendency in the nerve-centres of locomotion to act in a definite manner may easily be shown by holding a very young infant so that its feet just touch the ground. The legs will be observed to be alternately drawn up and planted on the ground. The care bestowed by the human being and by many of the higher animals on their young militates against their early acquirement of the power of locomotion, but in other instances the nervous and muscular systems are so developed and co-ordinated as to act together at once harmoniously. Thus, as soon as

a chicken is hatched it will run, and if a few grains of corn be thrown to it, it will pick them up with unerring certainty. The young of a dog or cat, or even of man is on the contrary utterly incapable of taking care of itself, either by avoiding danger or by procuring its own food, beyond knowing how to suck. We may surmise that the difference is due to the fact that in the former case the acts of the adult bird being few and similar in their nature throughout life, the structure of the nervous system and of the muscular apparatus of the body is complete at or before the time of emergence from the egg, and is at once ready to act in an automatic manner as soon as it is excited by an appropriate stimulus. The brain of the infant, on the other hand, though far larger than that of the chick, is in a less developed state, and it is only after many trials that the appropriate muscular efforts can be co-ordinated. The instinctive acts occupy a position on the border-land between pure reflex or excito-motor acts, and those which result from the exercise of reason. Like the simple reflex acts they require no education, whilst they are admirably adapted to the purpose in view. At the same time they are sometimes performed in obedience to a stimulus which is clearly a misconception, as when a carrion fly lays its eggs in the flower of the ill-smelling stapelia. They are, however, far more under the influence of the

will than simple excito-motor acts, and are frequently modified in adaptation to changes in the surrounding conditions.

Another volume of this series will be devoted to the mind and its operations, which will deal with the higher faculties of the nervous system; but it may here be stated that of late years much evidence has accumulated tending to show that just as separate centres exist in the spinal cord and medulla oblongata which preside over special acts and functions, so the vast mass of nervous tissue which we call the brain is composed of an aggregation of special centres, each having its own definite function. These centres must not be regarded as isolable by the knife of the anatomist, but as areas of specialised nerve-cells, associated together by very close bonds of union, and ministering to the same purpose; but which are also connected by a thousand threads of communication with other parts of the nervous system, both centric and peripheral, so that they may be excited to action by stimuli acting on the extremities of sensory nerves, and also by stimuli proceeding from other centres; and it is hence possible that in cases of disease or injury affecting these cords of communication, the centres in question may cease to respond to stimuli of one kind, whilst they preserve their excitability and readily respond to stimuli coming from another source. The accompanying diagram

represents the brain of a dog with some of the sensory centres indicated. It will be observed that there is a small spot A, which is shaded, and which may be regarded

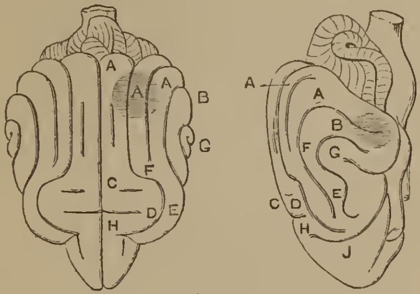


Fig. 31.

Brain of Dog.

A, visual centre; B, auditory centre; C–J, sensory centres; D, region of anterior limb; C, region of posterior limb; E, region of head; F, region of eyes; G, region of ears; H, region of neck; J, region of trunk.

as the chief seat of the intellectual or psychical centre of vision; for if this be destroyed, the animal whilst still able to guide itself and to see and avoid objects, is unable to appreciate their significance. It sees the vessel containing water from which it is accustomed to drink, but only drinks when it has by chance plunged its head into it. It sees the whip but ceases to fear it. In like manner the region shaded and marked B is the psychical centre of

audition, for if this region of the cortical part of the brain be diseased or injured, the animal loses its power of understanding the import of sounds to which it has been accustomed to respond. Yet it is not deaf, for it will continue to prick its ears at even a slight sound. After the lesion it no longer comprehends what is said to it, so that if previously taught to jump or beg at word of command, it will no longer do so when told. Many areas have thus been mapped out on the surface of the brain, which, like the above, have been named in accordance with their function, some being sensory, others motor. Dr. Ferrier has defined with great exactness the centre for movements for the hind and for the fore limb, the centre for the movements of the ear and tail, and so on. The interesting fact which seems to be the outcome of these researches is that not only every movement, but every thought and emotion, and even every effort of the will is in reality of a reflex nature, requiring a stimulus in order to start the process, and responding when such a stimulus is applied in a definite manner; varying, however, with the nature and strength of the stimulus, experiencing exhaustion when over-stimulated, and recovering after rest: and in fact, in all essential particulars, precisely resembling the ordinary reflex acts. There is no such thing as a purely automatic nervous act. Were it possible to rear an animal in darkness, silence, and without any excitation

of its various senses, it would have no ideas—it would be in the condition of a watch that has never been wound up —organically fit for work, but destitute of the motive or stimulus to action.

To maintain the nervous system in a healthy condition it is requisite that it should be kept in moderate activity during waking hours, and that the amount of sleep should be commensurate with the strain that has been made upon it, seven hours of rest being about an average quantity. A sufficiency of appropriate food is required, and this should be simple, in excess of the actual waste, and varied. Alcoholic stimulants, except in cases of exhaustion, are not required, and should never be taken by the young. A free supply of oxygen is of vital importance; heated rooms, crowded assemblies, impure air of all kinds, impair its functions and deteriorate its powers. As the nervous system is powerfully influenced by habit, that which has once been done being done more easily a second time, and still more easily after frequent repetition, as may be seen in the executive facility of every handicraftsman and in the feats of memory that may be accomplished by practice, it is of great importance that in the education of childhood the habits inculcated should be those that tend to develop the moral attributes and the higher qualities of the mind. In childhood, the brain, if the expression may be used, is plastic, and whilst it preserves throughout life in-

herited peculiarities and powers, it is yet capable of being moulded so that the lower or purely animal or sensual dispositions may be suppressed or controlled, whilst the higher attributes may be cultivated and improved. The cells of which it is composed, and which by heredity possess connections and fibres of communication with certain centres, can by instruction and exercise develop other connections which may dominate over the former and keep them in subjection. The memory, which is exceedingly vivid and tenacious in childhood, should always be carefully exercised and cultivated, since it tends to widen our associations and sympathy with surrounding objects; and for a similar reason, in the education of youth, whilst a close and somewhat severe course of training in any one subject, whether a language or some branch of biology, must be acknowledged by all to be of the utmost service in developing the mind, it is also advantageous that some, even though a very limited and superficial knowledge, should be gained of other and wholly dissimilar subjects, as music, or chemistry, or draughtsmanship.

It is a trite saying that the child is father to the man, but this signifies only that those habits of thought which are early instilled tend to become more and more deeply engrained, and hence the importance of inculcating attention to work, accuracy, alertness, promptitude, and

decision of character, if the man is to possess those qualities which conduce alike to his own happiness and success in life, and to the well-being of others.

Between the ages of ten and seventeen the young of both sexes are usually at school, and it is to be feared that in many cases, either from economy or from ignorance, the dietary is insufficient or inappropriate. Yet at no period is it more important that it should be wholesome and abundant. The tax upon the constitution occasioned by growth alone, which at this period is often astonishingly great, itself demands large supplies, and still more is needed, when in addition the powers of the nervous system are severely strained by exercise and by school-work. Girls in particular are frequently underfed and overworked; yet they rarely complain of hunger. They become pale and listless, and none of their bodily functions are properly performed. When such signs of failing health are observed the hours of study should be reduced, and the food given should be well dressed and tasty. It should be impressed on all those who have to learn much by heart, that more can be done by close attention for an hour than by a much longer period of inattention or careless work, and work should never be continued when exhaustion is felt. In mid-life the strain and anxiety of business or of a profession, the struggle for existence, tends to break down

the nervous system, but the actual giving way may often be traced to imperfect supply of nourishment and inadequate rest. Hence meals should be regular, and an occasional holiday is time gained, not lost. In old age the calls on the nervous system are fewer, and decay sooner or later sets in, but still he is most likely to preserve his faculties longest who exercises them moderately, and who at the same time maintains his general health by good food, exercise and sleep.